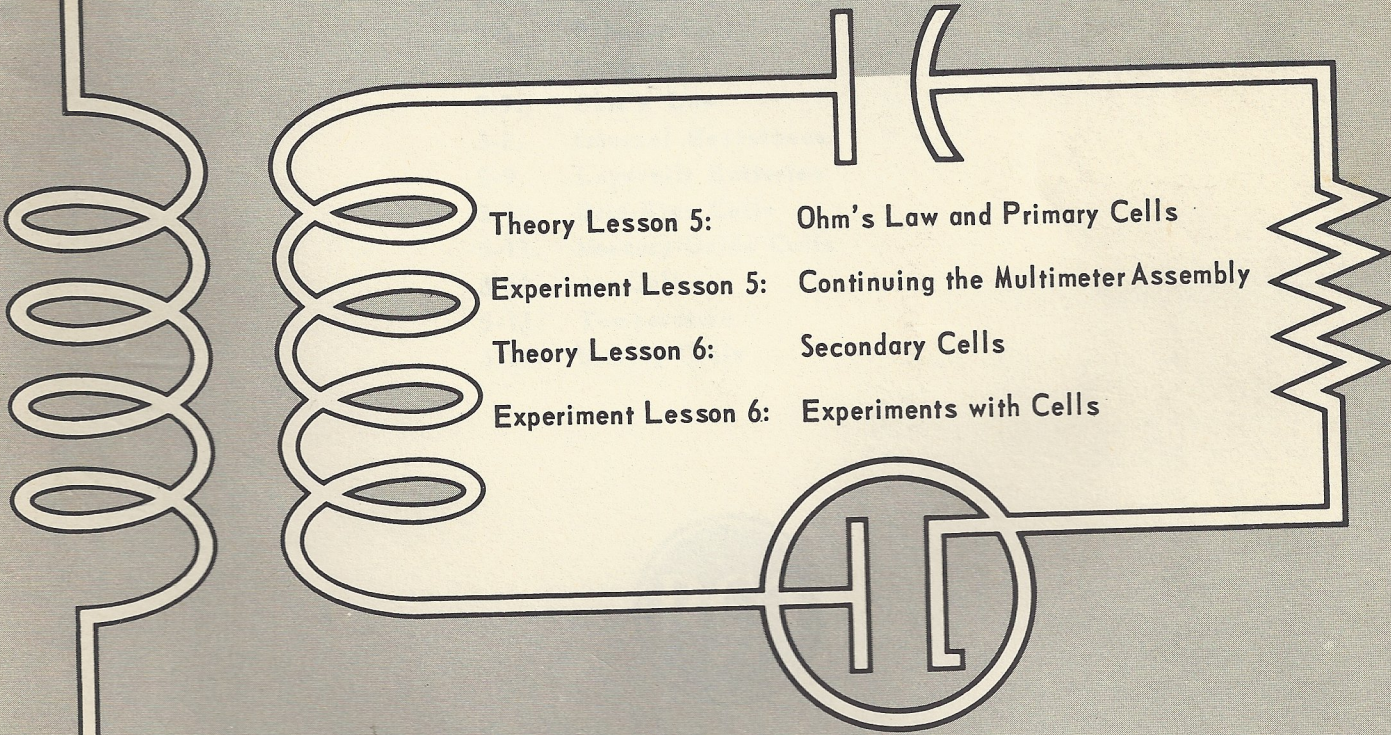


ELECTRONIC FUNDAMENTALS



Theory Lesson 5: Ohm's Law and Primary Cells
Experiment Lesson 5: Continuing the Multimeter Assembly
Theory Lesson 6: Secondary Cells
Experiment Lesson 6: Experiments with Cells

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA
New York, N. Y.



ELECTRONIC FUNDAMENTALS

THEORY LESSON 5

OHM'S LAW AND PRIMARY CELLS

- 5-1. Basic Electrical Units
- 5-2. Voltaic Cell
- 5-3. Electromotive Series of Metals
- 5-4. Chemical Action of a Cell
- 5-5. Primary Cell
- 5-6. Batteries
- 5-7. Ohm's Law
- 5-8. Internal Resistance
- 5-9. Layerbilt Batteries
- 5-10. Grid-Bias Cells
- 5-11. Mercury-Oxide Cells
- 5-12. Air-Cell
- 5-13. Temperature
- 5-14. Storing Cells



RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

350 West 4th Street, New York 14, N. Y.

Theory Lesson 5

INTRODUCTION

In the last lesson, we learned that when a difference in electric pressure exists between two points, and a conducting path connects them, an electric current will flow. We learned, too, that the flow of electrons is from the point of negative charge to the point of positive charge. Of course, if the flow is between two charged bodies, the current flow will stop as soon as the charge between the charged bodies becomes equal. When a conducting path connects the negative and positive terminals of a battery, however, the current flow is not momentary, but continues as long as the conducting path remains connected, or until the battery wears out or becomes discharged. Because this current always flows in the same direction, we call it *direct current*. There are other kinds of current, which will be discussed in another lesson.

5-1. BASIC ELECTRICAL UNITS

Just as we need units like ounces and pounds, inches and feet, and pints and quarts to measure many things we use daily, so do the electrician, the serviceman, and the engineer need units to measure electricity. Certain standard units have been adopted and are in use all over the world. No matter what country you visit, for instance, *volt* stands for the same amount of electrical pressure and *ampere* for the same rate of flow. Some of the more important units we must know something about are the *coulomb*, the *ampere*, the *volt*, the *ohm*, and the *watt*.

The *coulomb* is a unit of charge. Just as we measure gasoline by the gallon, we measure electrons by the coulomb. An electron is so very, very small an electrical charge that a tremendous number of electrons

must flow in circuits to light lamps, operate radios, and run motors. The coulomb represents 6,240,000,000,000,000,000 electrons; that's 6.24 quintillion electrons. Remember that the coulomb is a unit of quantity.

$$6.24 \times 10^{18}$$

The *ampere* is the unit that represents the rate of flow of electric current. An ampere of current is flowing when one coulomb of electricity passes any point in an electric circuit in one second. For instance, if 6.24 quintillion electrons flow through an electric lamp in one second, the rate of flow is one ampere. To understand the difference between coulombs and amperes, we might compare them to liquid measures. If you pour a gallon of water into a pail, you have a quantity of water. You don't care how fast the water goes into the pail. But if you are watering the lawn with a hose attached to a water tap, and someone asks you how much water you are using, you start figuring how many gallons per minute are coming out of the hose. The coulomb, like the gallon, is a measure of quantity. The ampere, like the gallons-per-minute, is a measure of rate of flow. (See Fig. 5-1.)

The *volt* is a measure of electrical pressure. It is the amount of pressure necessary to force one ampere through a circuit that has a resistance of one ohm. From now on, we'll speak of electrical pressure as *emf*, *potential difference*, or *voltage*.

The *ohm* is the unit of electrical resistance. Resistance opposes the flow of electric current. The *ohm* is the amount of resistance offered by a circuit when one ampere flows and the pressure across the circuit terminals is equal to one volt. The symbol for the ohm is the Greek letter Ω (omega). If there were such a thing as a perfect conductor, we would have a circuit

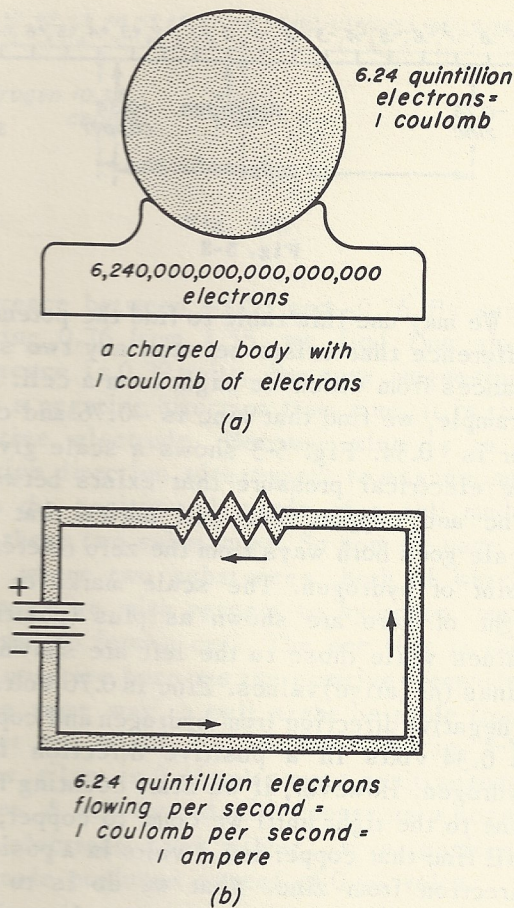


Fig. 5-1

without resistance. However, the perfect conductor does not exist, since even the best conducting materials offer some opposition (resistance) to the flow of current. There are three circuit properties or characteristics about which we are going to study quite a lot. They are: *resistance*, *inductance*, and *capacitance*. When we understand what happens when these properties are present in an electric circuit, we are well on the way to an understanding of radio principles.

The watt is the unit of measure of electrical power. Another word, *energy*, sometimes is mistakenly used instead of *power*. Let us see how they differ. Energy is the ability to do work. Power is the rate of using energy, or energy per unit of time. You might have an electric motor, with ample electrical energy to run it, but if you don't turn the switch no work is done and no power is consumed. The electrical unit of power, the

watt, is defined as the rate at which energy is used when an emf of one volt causes one ampere to flow through a circuit.

5-2. VOLTAIC CELL

As you learned in the last lesson, we may obtain electricity in several ways. We may produce electricity by means of friction, by chemical action, by electromagnetic machines, by heating unlike metals that have been joined together, and in less common ways. This lesson is about the chemical methods of producing electricity.

Back in 1798, an Italian scientist, Alessandro Volta, discovered that, by placing a strip of zinc and a strip of copper in a jar containing dilute acetic acid (vinegar), as shown in Fig. 5-2, he could produce electricity. He found that a difference of electrical pressure existed between the zinc and the copper. He didn't know how much the pressure was because at that time there

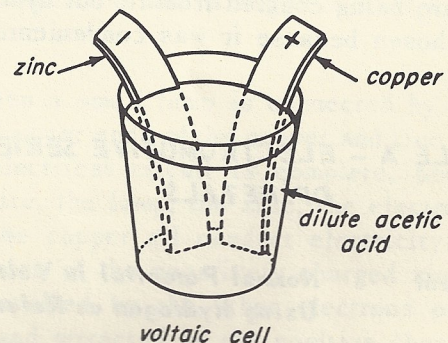


Fig. 5-2

were no electrical units with which to measure electricity. Later on, other men discovered the difference to be about 1.1 volts. As you might guess, the unit of electrical pressure is named after Volta.

One very important fact discovered by Volta was that electricity could be produced only between two unlike substances (usually metals). If, for instance, two copper or two zinc rods were placed in the fluid in the jar, no voltage was produced.

5-3. ELECTROMOTIVE SERIES OF METALS

Following Volta's experiments, other scientists learned that the amount of voltage produced by a cell made up of any two substances could be accurately predicted. Table A shows a table of some common substances and the electrical pressure that exists between them when they are placed in an alkaline, acid, or salt solution.

If you look at Table A, you will see that each substance is followed by a number that represents the difference in electrical pressure that exists between it and hydrogen. In electricity, radio, or chemistry, we say that hydrogen is used in this table as a *reference point* (a position from which things are counted). So, for this table, hydrogen is zero. Lead, tin, iron, etc. are negative with respect to hydrogen. Bismuth, copper, mercury, etc. are positive with respect to hydrogen. Any one of the substances shown in this table could have been used as the reference with all the differences in electrical pressure being counted from it, but hydrogen was chosen because it was convenient.

TABLE A - ELECTROMOTIVE SERIES OF METALS

Element	Normal Potential in Volts Using Hydrogen as Reference
Potassium	-2.92
Sodium	-2.71
Magnesium	-1.55
Zinc	-0.76
Iron	-0.44
Tin	-0.13
Lead	-0.12
Hydrogen	0.00
Bismuth	+0.20
Copper	+0.34
Mercury	+0.80
Silver	+0.80

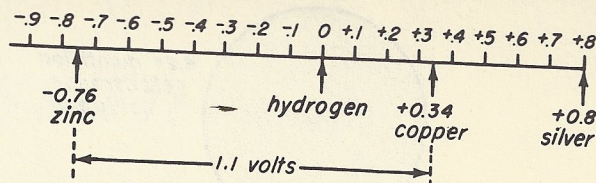


Fig. 5-3

We may use this table to find the potential difference that exists between any two substances from which we might form a cell. For example, we find that zinc is -0.76 and copper is $+0.34$. Fig. 5-3 shows a scale giving the electrical pressure that exists between zinc and copper. You will notice that the scale goes both ways from the zero reference point of hydrogen. The scale marks to the right of zero are shown as plus (positive) values while those to the left are shown as minus (negative) values. Zinc is 0.76 volts in a negative direction from hydrogen and copper is 0.34 volts in a positive direction from hydrogen. However, if we start counting from zinc to the right until we come to copper, we will find that copper is 1.1 volts in a positive direction from zinc. What we do is to add -0.76 and $+0.34$ without worrying about minus and plus signs and we get 1.1 . This tells us the difference in voltage (electrical pressure) that exists between zinc and copper. Because copper is in a positive direction from zinc, it is the positive electrode of the cell, and zinc is the negative electrode of the cell.

However, if we make a cell with zinc and magnesium as the two electrodes, we can see in Fig. 5-4 that zinc is 0.76 volts in a minus direction from hydrogen and magnesium is 1.55 volts in a minus direction from hydrogen; the difference in pressure that exists between magnesium and zinc is the

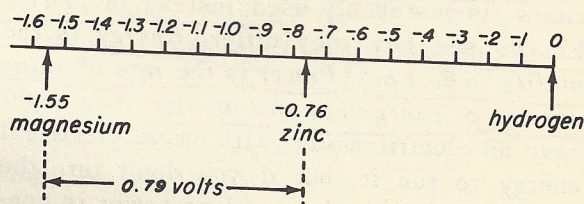


Fig. 5-4

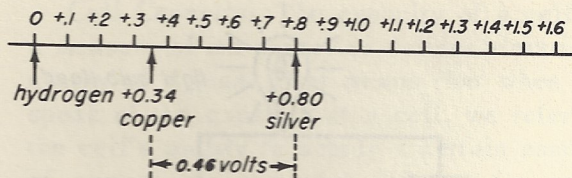


Fig. 5-5

difference between -1.55 and -0.76 . By subtracting 0.76 from 1.55 , we find that this difference is 0.79 volts. Because magnesium is in a negative direction from zinc, it is the negative electrode. Because zinc is in a positive direction with respect to magnesium, it is the positive electrode of a cell made from these two substances. So now we have a case where two substances, both of which are negative with respect to hydrogen, may be used to form a cell. The one that is the less negative becomes the positive electrode. In the same way, a cell might be made from copper and silver. As the scale in Fig. 5-5 shows, silver is 0.46 volts more positive than copper. A cell formed with copper as a negative electrode and silver as a positive electrode produces an emf of 0.46 volts.

From the electromotive series table, you can see that the emf produced by chemical action between two metals or other substances placed in an acid, alkaline, or salt solution of proper strength is determined by the metals used. The size of the cell, the amount of the metals, and the spacing of the metals does not affect the emf produced by chemical action.

5-4. CHEMICAL ACTION OF A CELL

You are probably interested in knowing how and why a cell produces electricity. The complete story is difficult to tell and, without a knowledge of chemistry, difficult to understand. In fact, even the people who make batteries cannot answer some of the questions we might ask about the chemical and electrical action in a cell. However, it is not necessary or particularly desirable that we, as servicemen, know more than a few basic facts about cells and batteries. For that reason, the following paragraphs do not attempt to go into the chemistry of a cell.

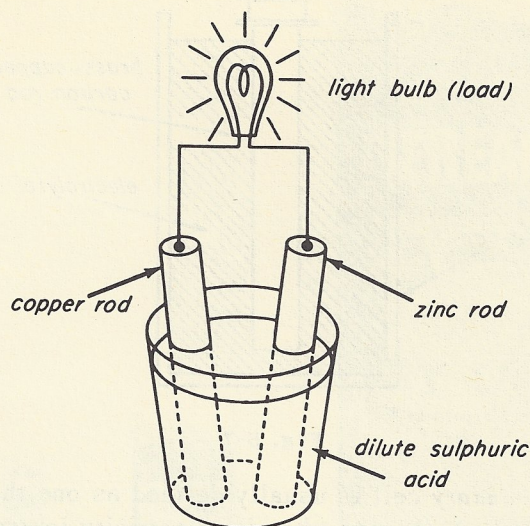


Fig. 5-6

Figure 5-6 shows a copper rod and a zinc rod in a jar containing sulphuric acid and water. The mixture of acid and water is called the electrolyte; without it there would be no cell action and no emf produced. The chemical action of the electrolyte upon the two metals produces a positive charge upon the copper rod and a negative charge upon the zinc rod.

When a small lamp is connected by wires to the upper ends of the copper and zinc rods, the electrical circuit is complete, because the wire, the lamp, the zinc, the electrolyte, and the copper all conduct electricity. The electrons of the negatively charged zinc rod are repelled by the other electrons on the zinc and attracted by the positive charge on the copper rod. Therefore, they move toward the copper through the connecting wires and the lamp – thus producing an electric current in the load circuit (outside the cell). This action continues until the circuit is broken by removing the lamp from the ends of the copper and zinc rods or until the zinc is eaten away by chemical action.

5-5. PRIMARY CELLS

Cells may be divided into two main classes: *primary* cells and *secondary* cells. By the term *primary* cell, we mean a unit that is consumed as it is used, while a

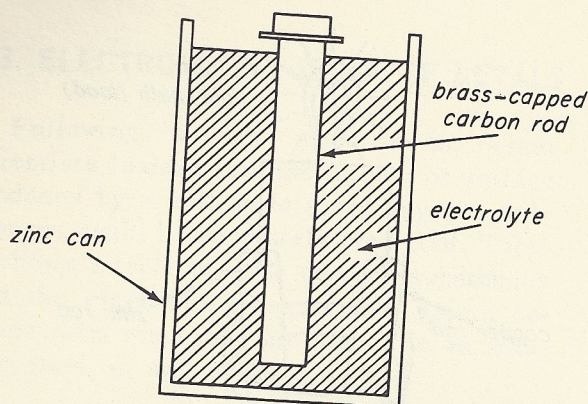


Fig. 5-7

secondary cell is usually defined as one that may be recharged when its electricity is used up.

Most primary cells used in this country are made from carbon and zinc and are called dry cells. This combination produces a cell that is normally rated at 1.5 volts, although some cells sometimes test a little higher.

Construction and Action of Carbon-Zinc Cell. As shown in Fig. 5-7, the container and negative electrode of a single carbon-zinc cell is made from zinc. The zinc is as free as possible from impurities. There is also a brass-capped carbon rod, which receives the positive charges and acts as the positive electrode. Between the carbon and zinc is the electrolyte, which is a paste made from ammonium chloride.

The action of the carbon-zinc cell is similar to that of the copper-zinc cell discussed before. The electrolyte acts upon the carbon and zinc to produce a positive charge on the carbon and a negative charge on the zinc. There is, however, another action not yet mentioned. While the cell is producing electricity, hydrogen bubbles gather on the carbon electrode, as shown in Fig. 5-8. When the carbon rod becomes coated with hydrogen bubbles, the flow of electricity slows down or stops completely, because the hydrogen acts to resist the chemical action between the carbon electrode and the electrolyte. When this happens, we say that the cell is *polarized*.

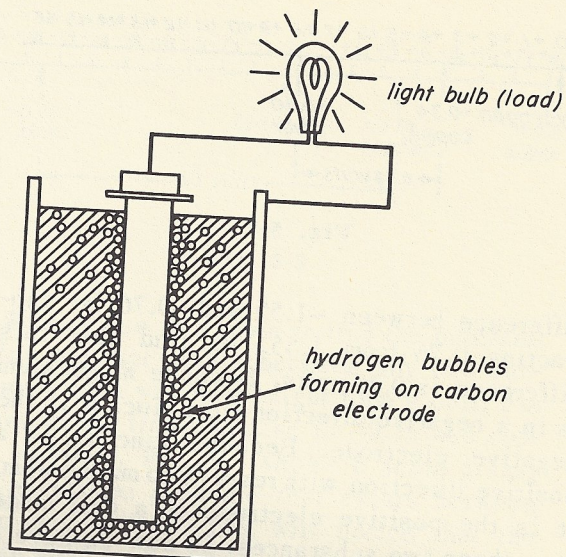


Fig. 5-8

Depolarizing Mix. It is necessary to add something to the cell that will get rid of the hydrogen bubbles as soon as they are formed on the carbon rod. So, in between the electrolyte and the carbon electrodes, as shown in Fig. 5-9, we insert a *depolarizing mix*, which contains a chemical called *manganese dioxide*. Some of the oxygen from this chemical combines with the hydrogen bubbles to form water, which leaves the carbon electrode free to gather more electrical charges, give up more electrons, and so remain positively charged.

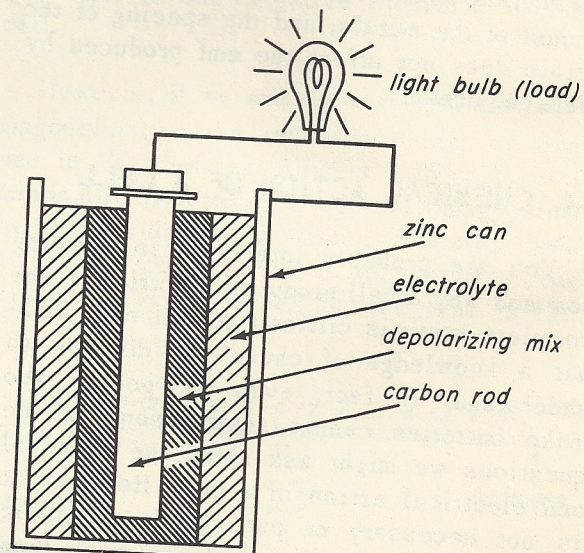


Fig. 5-9

Cell Capacity. The capacity of a cell is a measure of its ability to deliver electrical energy to a load. This means that when we speak of the capacity of a cell, we refer to the cell's ability to supply a certain amount of current, at a useful voltage, for some period of time. Each cell that is made today is designed for a certain load.

The ability of a cell to supply any desired amount of current is determined by the amount of surface area of each electrode that is exposed to the electrolyte and to the kinds and quantities of the materials that make up the depolarizing mix.

In the case of the carbon and zinc cell, the capacity of the cell is affected by the number of square inches of zinc and the number of square inches of carbon touched by the electrolyte. Therefore, none of the outside area of the zinc helps supply electricity, because it is not exposed to the electrolyte. Only that part of the inner surface of the zinc that actually touches the electrolyte can affect the capacity. In the same way, only the surface of the carbon electrode that is in actual contact with the electrolyte can affect the cell's capacity. The capacity of modern cells has been increased by mixing carbon in the depolarizing mix. This exposes a much larger area of carbon to the electrolyte.

There is no exact way of measuring the capacity of a cell. In other words, we cannot set an exact figure for the amount of electricity that may be obtained from a particular cell. There are many factors that determine how fast, and for how long a time, a cell can supply electrical power. Much depends upon the kind of service for which the cell is designed, and the kind of load that is connected to it. In general, under normal conditions, we can draw more current from a large cell than from a small cell. (There are exceptions to this rule.) Figure 5-10 shows the relative sizes of three types of cells. Also, some cells are made for continuous duty, while other cells are made to be used for short periods at a time. For that reason, we must know the kind of service for which the cell was designed.

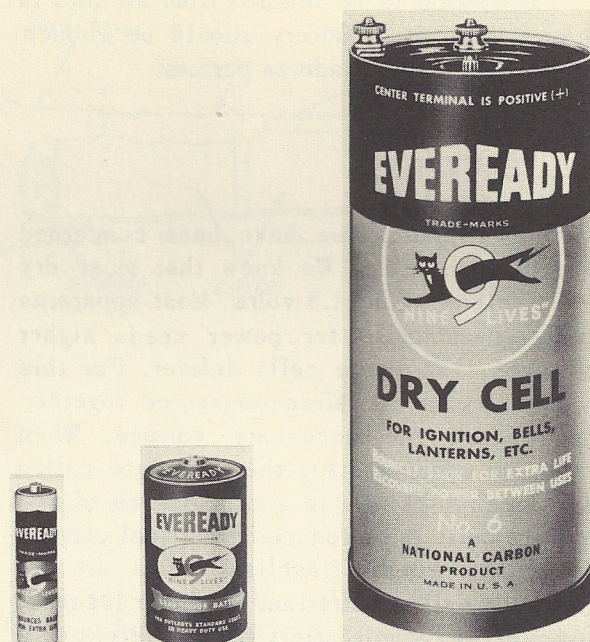


Fig. 5-10

If we attempt to draw electricity from the cell at a rate greater or for a period longer than it was designed to deliver, the depolarizing agent cannot get rid of the hydrogen bubbles on the positive electrode as fast as they are formed. When this happens, the output voltage of the cell drops, and it does not rise again until the cell has "rested". You may have used a flashlight continuously at some time or other until the light grew very dim. Later on, you picked up the flashlight and found it working again. All that happened was that the cells were given time to depolarize.

On the other hand, if we draw electricity from a cell at a rate much slower than it was designed for, we may get less service out of the cell than it was designed to give. This is due to losses caused by the chemical actions that take place when a cell stands idle. For example, the *shelf life* (the period during which the cell can deliver from 80-95% of full capacity) of all but the very small dry cells (such as the pen-light size) is about two years. If we were to draw electricity from such a cell at so slow a rate that it was still in service after two years, some of the capacity of the cell would be lost in the chemical actions that naturally occur when a battery or cell stands idle.

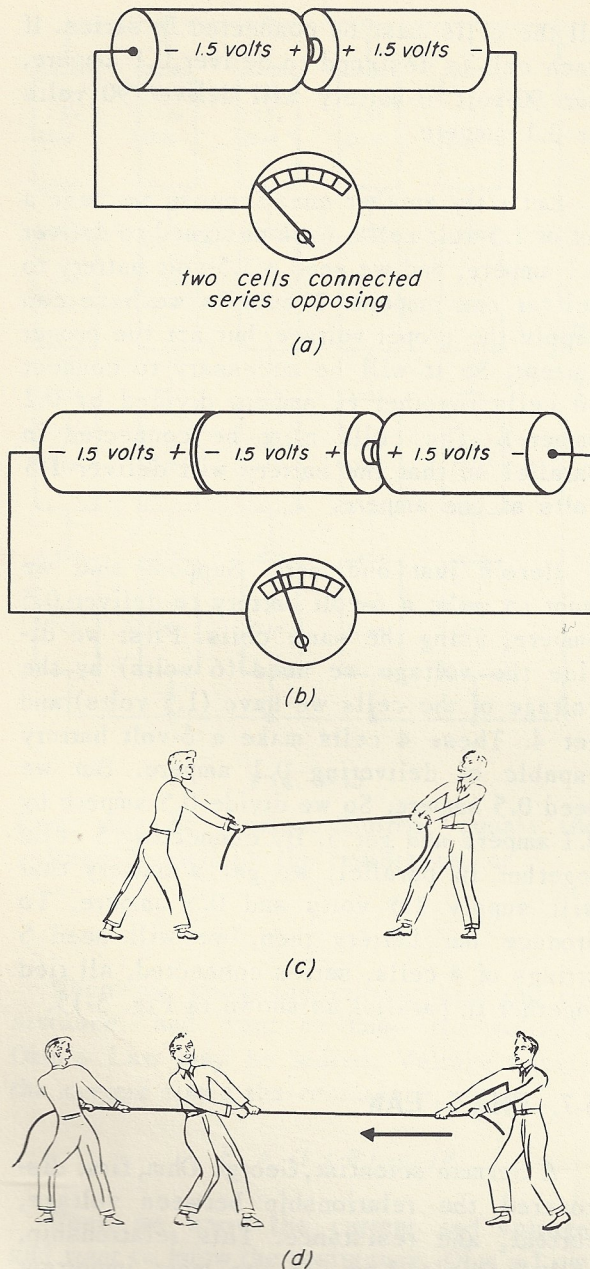


Fig. 5-12

the single cell. The resulting electrical pressure is the pressure of one cell exerted in the direction of the two cells.

If you have a 2-cell flashlight, try reversing one of the cells so that the negative terminal of one is connected to the negative terminal of the other. You will find that the flashlight will not light, because the voltage of one cell is cancelled by the voltage of the other cell in the opposite direction. So you can see that it is very important to connect

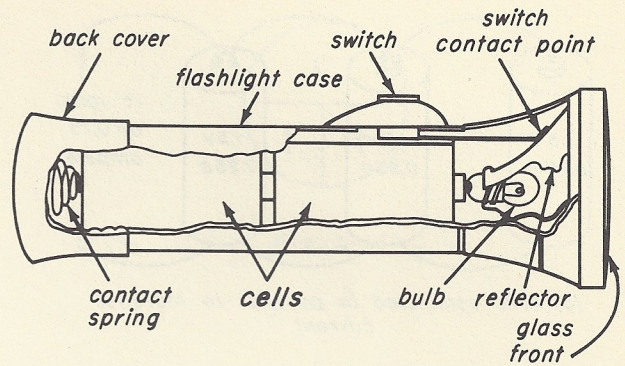


Fig. 5-13

cells in the proper way in order to get the voltage of one cell to add to the voltage of the next cell.

Carbon-zinc dry cells are connected together in series to form batteries of various voltages; many of these batteries are made specially for radio. However, one of the most common uses of dry cells connected in series is in 2-, 3-, or 5-cell flashlights. The 2-cell flashlight needs three volts to give maximum light; when we put cells in the flashlight case, we place them so that the positive electrode of one cell presses against one terminal of the flashlight bulb and the positive electrode of the second cell presses against the negative electrode of the first cell. This is shown in Fig. 5-13. The negative electrode of the second cell makes contact through the pressure spring, the metal case, and the switch to the other terminal of the bulb.

Cells Parallel Connected. When cells are connected in series to increase the voltage, there is no increase in the amount of current that may be drawn from the series over the amount of current that may be drawn from each individual cell. This means that if the cells are rated to deliver a quarter of an ampere continuously, this rate is not increased by connecting them in series. We can still draw only a quarter of an ampere safely. To increase the current-producing capacity, it is necessary to connect cells in parallel, as shown in Fig. 5-14a. For example, if one cell safely delivers a quarter of an ampere continuously, two cells in parallel will deliver half an ampere, and

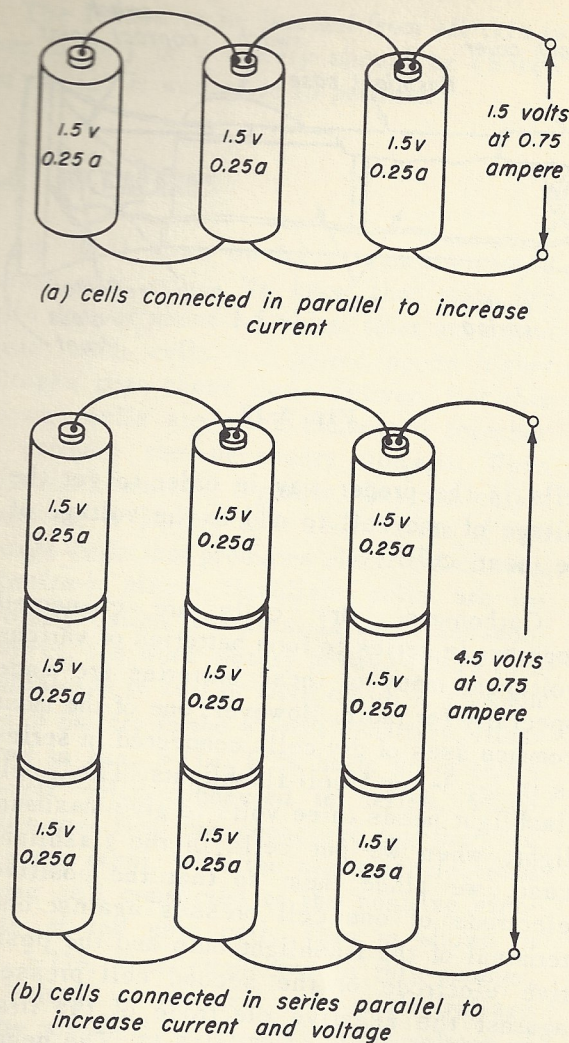


Fig. 5-14

so on. If we need to increase the voltage and the current at the same time, we must connect the cells together in series-parallel (to increase current-producing capacity), as shown in Figure 5-14b.

Let's try a few examples so we can see how to figure the number of cells needed to make a battery to supply a particular need. For example, suppose a 90-volt B-battery is needed for a portable radio and all we have is a supply of 1.5-volt cells. How many cells are needed and how must they be connected? To find the answer, we must find out how many times 1.5 volts goes into 90 volts. So we divide 90 by 1.5. We find that the answer is 60. So, 60 1.5-volt cells will be needed, and, because the voltage of one cell must add to the voltage of the next cell,

all the cells must be connected in series. If each cell is designed to deliver 0.1 ampere, our 90-volt B-battery will deliver 90 volts at 0.1 ampere.

Let's try another one. Suppose we have a lot of 1.5-volt cells, each designed to deliver 0.1 ampere, and we need a 1.5-volt battery to deliver one ampere. The cells we have can supply the proper voltage, but not the proper current. So it will be necessary to connect 10 cells together (1 ampere divided by 0.1 ampere). The cells must be connected in parallel so that the battery will deliver 1.5 volts at one ampere.

Here's just one more. Suppose that we want to make a 6-volt battery to deliver 0.5 ampere, using the same cells. First we divide the voltage we need (6 volts) by the voltage of the cells we have (1.5 volts) and get 4. These 4 cells make a 6-volt battery capable of delivering 0.1 ampere. But we need 0.5 ampere. So we divide 0.5 ampere by 0.1 ampere and get 5. By connecting 5 cells together in parallel, we get a battery that will supply 1.5 volts and 0.5 ampere. To produce our battery then, we will need 5 strings of 4 cells, series connected, all tied together in parallel as shown in Fig. 5-15.

5-7. OHM'S LAW

A German scientist, George Ohm, first discovered the relationship between voltage, current, and resistance. This relationship, called Ohm's Law, is the most important principle in all electricity.

In any electrical circuit, the current in amperes is equal to the emf in volts divided by the resistance in ohms. When applying Ohm's Law to our work, we use the following abbreviations:

E = Volts

I = Amperes

R = Resistance in ohms

Ways to Write Ohm's Law. Thus, Ohm's

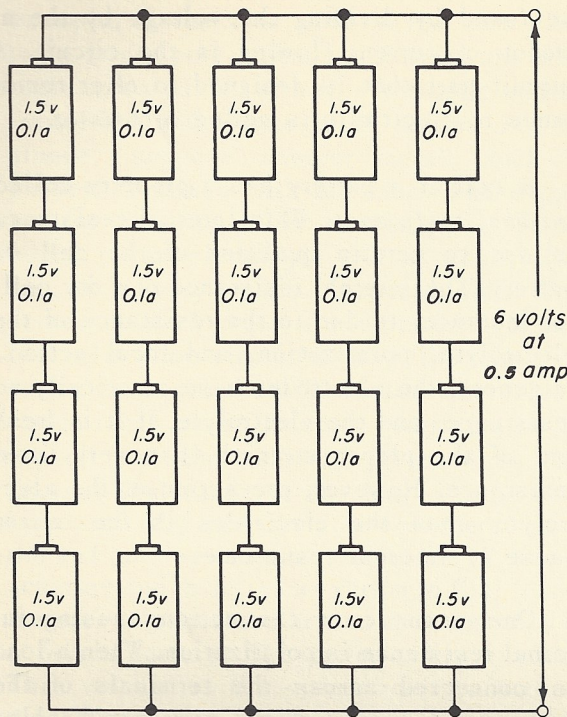


Fig. 5-15

Law may be written: Current equals the voltage divided by the resistance, or

$$I = \frac{E}{R}$$

When we know the current and the resistance, and want to know the voltage, Ohm's Law may be stated: Voltage equals the current times the resistance, or

$$E = (I \times R) = IR$$

When we know the current and voltage and want to know the resistance, Ohm's Law becomes: Resistance equals the voltage divided by the current, or

$$R = \frac{E}{I}$$

You can use the same little circle trick you used to solve wavelength and frequency problems to solve Ohm's Law problems. The circle to set up looks like the one in Fig. 5-16. You cover the term you want to find, and what remains is the answer. For example, to find E , you cover E in the circle and IR remains. Then you know that $E = IR$. Likewise, if you cover I , you can see that

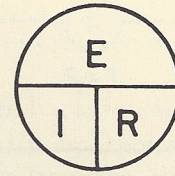


Fig. 5-16

$$I = \frac{E}{R}$$

and when you cover R , you see that

$$R = \frac{E}{I}$$

Application of Ohm's Law. Now that Ohm's Law has been stated, let us see how we can use it. Figure 5-17a shows a simple electrical circuit: a resistor connected across the terminals of a battery. The resistor has a resistance of 30 ohms and the battery has a voltage of 60 volts. To calculate how much current is flowing, we use the formula:

$$I = \frac{E}{R}$$

$$I = \frac{60}{30}$$

$$I = 2 \text{ amperes}$$

Suppose that we know the current to be 12 amperes and the resistance to be 10 ohms, as shown in *b* of the figure. We may find the voltage by:

$$E = I \times R$$

$$E = 12 \times 10$$

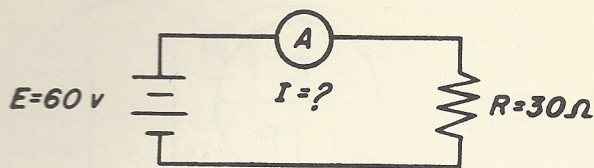
$$E = 120 \text{ volts}$$

If the current is 15 amperes and the voltage is 105 volts, as in *c* of the figure, we find the resistance as follows:

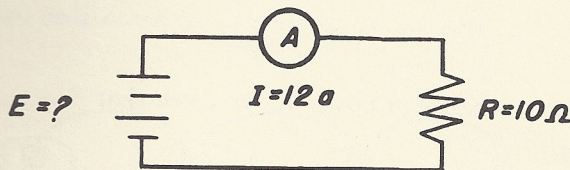
$$R = \frac{E}{I}$$

$$R = \frac{105}{15}$$

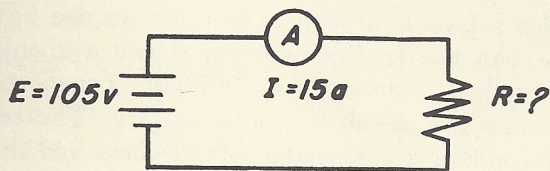
$$R = 7 \text{ ohms}$$



(a)



(b)



(c)

Fig. 5-17

5-8. INTERNAL RESISTANCE

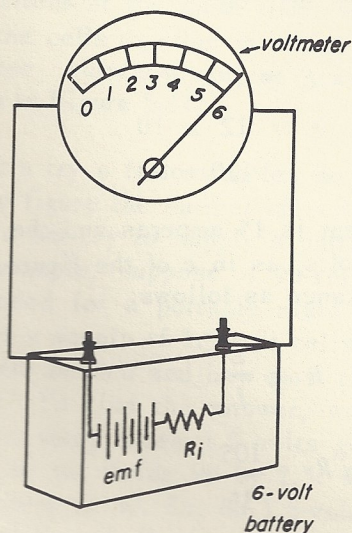
Earlier in this lesson, it was said that resistance is the property of a circuit that opposes the flow of current in the circuit; that is, resistance tends to stop current from flowing. Even silver and copper, two of the very best conductors of electricity, offer some resistance to the flow of electricity. As we know, resistance is measured in ohms. According to Ohm's Law, the resistance can

be found by dividing the voltage by the amount of current flowing in the circuit. A circuit part that is designed to offer resistance to electricity is called a *resistor*.

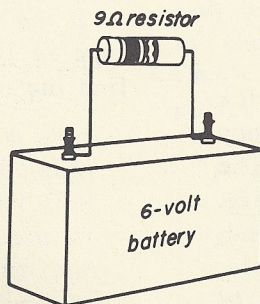
A cell or a battery has a property called *internal resistance*. This internal resistance is due to certain qualities of the cell or battery. The internal resistance of a dry cell, for instance, is due to the resistance of the electrolyte, polarization, and local action. In general the electrodes have practically no resistance, and the electrolyte, if it is fresh and of the proper strength, has very little resistance. However, the action of the electrolyte upon the electrodes is the major cause of internal resistance.

One example of the action causing internal resistance is polarization. When a load is connected across the terminals of the battery and current flows, hydrogen bubbles form on the positive electrode and slow down the chemical action of the battery. When the chemical action is slowed down, the battery cannot deliver as much voltage to the load. This is because some of the emf produced by chemical action is lost inside the battery. In other words, the internal resistance of the battery has been increased, and a greater portion of the emf is dropped across it.

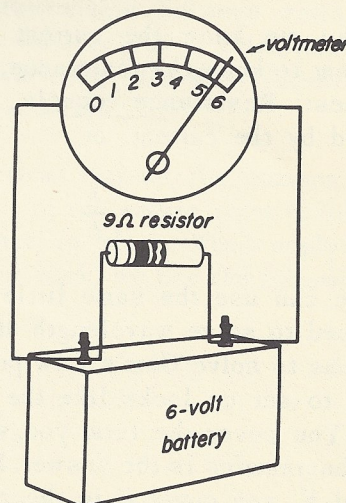
Another cause of internal resistance is *local action*, caused by impurities in the substances used in making the battery. For



(a)



(b)



(c)

Fig. 5-18

Resistors in series divide voltage current throughout series circuit is the same

Internal Resistance

13

example, if the zinc used in the zinc electrode is not pure — that is, if there are other substances mixed with it — the zinc and its impurities will cause local action. For instance, suppose another metal, such as copper, is mixed with the zinc. The copper and the zinc are unlike metals. Both are exposed to an electrolyte. As a result, they act as a very small electrical cell. Connected to each other, the electrodes of this cell are short-circuited, and the chemical action is continuous. The area where local action takes place does not contribute to the capacity of the cell. In other words, the internal resistance of the battery has been increased. A battery may be considered as if the emf and the internal resistance (R_i) were separate and in series as shown in Fig. 5-18a. A meter is connected across the terminals of a 6-volt battery. The meter reads 6 volts. This voltage is the *open-circuit voltage* of the battery; that is, the meter is measuring the voltage of the battery when no load is connected across it and, therefore, no current is being drawn. In Fig. 5-18b, a 9-ohm resistor is connected across the battery. This is to provide a load so that current can flow. When we measure the voltage across the battery terminals with the load connected across them, as shown in Fig. 5-18c, we are measuring the *closed-circuit voltage*, or *terminal voltage*. The terminal-voltage reading is 5.4 volts. This is 0.6 volt lower than the open-circuit voltage. The voltage has dropped 0.6 volt due to the internal resistance of the battery.

These measurements show us that terminal voltage is equal to the open circuit voltage less the voltage that is lost inside the cell due to internal resistance. The terminal voltage is the usable voltage of the cell. Naturally, it is best to keep internal resistance down so that terminal voltage will be as high as possible.

We can find the internal resistance of a cell for any particular load of a cell or battery. We must know what the load is so that we may know how much current is being taken from the cell or battery. As we know, when the load is very great and more current is drawn than the cell or battery is designed

to deliver, polarization will occur faster and increase internal resistance.

The internal resistance may be found fairly accurately by subtracting the closed-circuit voltage from the open-circuit voltage and dividing the difference by the current flowing. Let's see why this is so. The open-circuit voltage is the emf developed by the battery. The closed-circuit voltage is the voltage at the terminal when a load, such as a 9-ohm resistor, is connected. The difference between these, of course, is the voltage drop inside the cell due to internal resistance. Ohm's Law tells us that the resistance of a resistor or of a part of a circuit may be found by dividing the voltage across the resistor or across that part of the circuit by the current flowing through the circuit. So, to find the internal resistance of a cell, we must also know how much current is flowing in the circuit when the load is connected. Then the internal resistance is found by dividing the voltage lost in the battery by the current flowing in the circuit. SERIES

For example, when we connected the meter to the 6-volt battery without a load, we measured the open-circuit voltage, which was 6-volts. When we read the meter after connecting the load, we found the closed-circuit voltage, which was 5.4 volts. The current in the circuit can be found by using Ohm's Law. The voltage across the resistor was 5.4 volts and the resistance of the resistor was 9 ohms. Therefore, the current flowing through the resistor and battery circuit is equal to 5.4 divided by 9. The answer is 0.6 ampere. The internal resistance equals the open-circuit voltage minus the closed-circuit voltage, divided by the current. This equals 6 minus 5.4 over 0.6. This equals 0.6 over 0.6, which equals 1 ohm. The internal resistance of the battery with a 9-ohm load resistor is equal to 1 ohm.

We can set up the problem we have just discussed in the following form.

Internal resistance (R_i)

$$= \frac{\text{open circuit voltage} - \text{closed circuit voltage}}{\text{current}}$$

Current (I)

$$= \frac{\text{voltage across 9-ohm resistor (E)}}{9 \quad (R)}$$

$$= \frac{5.4}{9}$$

$$= 0.6 \text{ amp.}$$

$$\text{Internal Resistance (R}_i\text{)} = \frac{6 - 5.4}{0.6}$$

$$= \frac{0.6}{0.6}$$

$$= 1$$

In fresh cells made by leading battery manufacturers, the internal resistance of a cell is very, very small, provided the cell is not overloaded or otherwise abused.

5-9. LAYERBILT BATTERIES

The cells we have been studying about up until now have all been cylindrical in shape. When batteries are made from such cells, a lot of space is wasted, as you can see for yourself in Fig. 5-19. Actually, between the space used inside each cell and the space wasted between cells, only about fifty percent of the space occupied by such a battery contains useful electricity-making

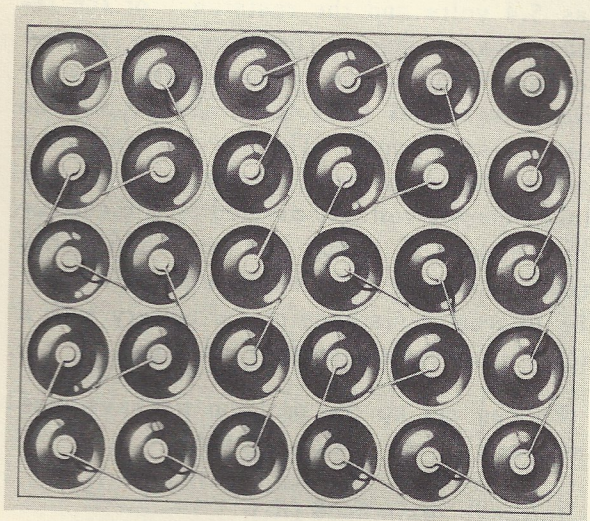


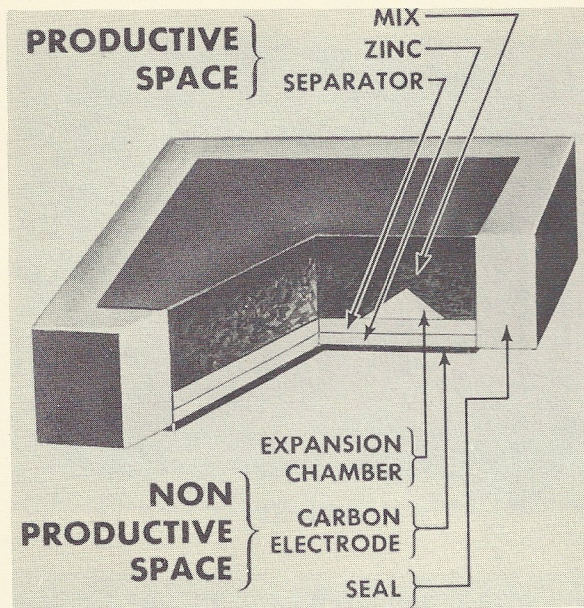
Fig. 5-19

materials. In order to conserve space and to make smaller batteries do the work of larger ones, one manufacturer developed the Layerbilt battery. Fig. 5-20a shows a cut-away view of a Layerbilt cell. It is a carbon-zinc cell like those we have been studying. However, instead of being cylindrical, each cell is square and flat, as shown in Fig. 5-20b. To form batteries, they are piled one on top of the other as shown in Fig. 5-20c. Two such stacks of 15 cells each are used to produce the familiar 45-volt B-battery used in so many portable battery-operated radios and shown in Fig. 5-20d.

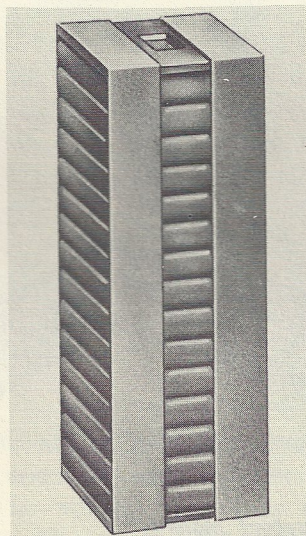
5-10. GRID-BIAS CELLS

Once in a while, in radio and television circuits, it is necessary to have a source of voltage just to act as a difference in potential. In such cases, no current is drawn. It is necessary that the cells that provide this voltage have long life with constant voltage have freedom from local action, and be small in size. Two types of cells of the same size and shape as the one shown in Fig. 5-21 have been used by radio manufacturers for many years. They are called *grid-bias* cells or, sometimes, *acorn* cells. One type has an outer container, shaped like an acorn and made of cadmium, that acts as the negative electrode. The electrolyte is an acid paste. The positive electrode is made of vanadium pentoxide, which is insulated from the cadmium container by an insulating grommet. The voltage developed by this cell is 1.04 volts. The other type of grid-bias cell is made in the same way, except that the container and negative electrode are made of zinc instead of cadmium. The voltage developed by this type of cell is 1.2 volts.

Grid-bias cells, used properly, maintain constant voltage for periods of from 5 to 10 years. Because they were not designed to provide current, care must be used to see that they are not accidentally shorted. Even testing one with a meter is not advisable; this tends to load the cell, and any readings obtained are likely to be inaccurate. However, these cells have the ability to return to approximately normal voltage after a momen-



(a)



(c)

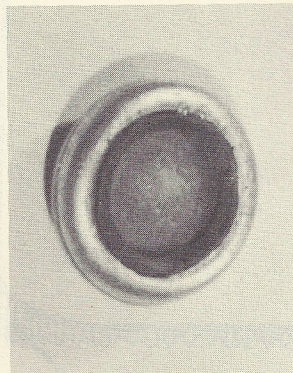
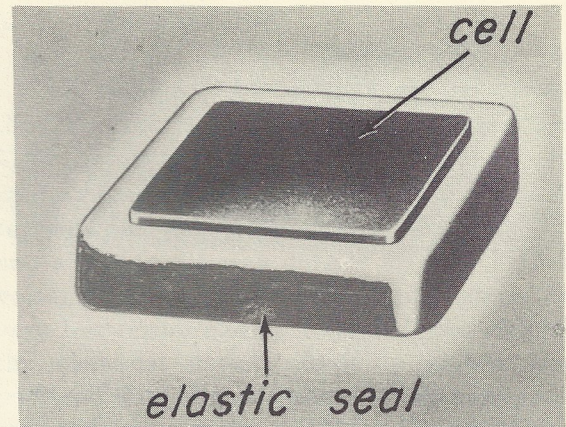
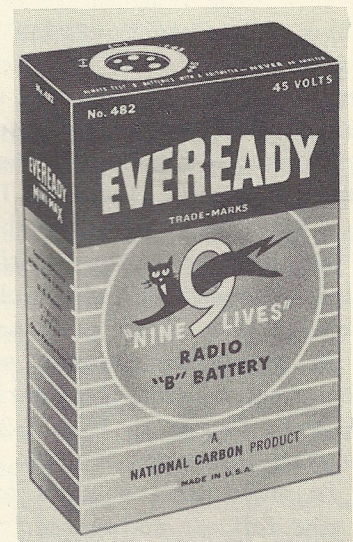


Fig. 5-21



3 The elastic seal is shrunk around the entire assembly, protecting the cell against loss of moisture and preventing creepage of solution from one cell to the next.

(b)



(d)

Fig. 5-20

tary short, which might easily occur while trouble shooting.

When more voltage is required than one cell can provide, cells may be connected in series to provide higher voltages. Special clip holders for these cells (shown in Fig. 5-22) are manufactured. Clip holders designed for two or more cells provide the connection between the cells.

5-11. MERCURY-OXIDE CELLS

Another type of cell, developed in recent years, is coming into common use. It is the

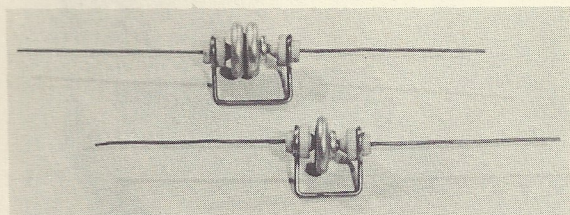


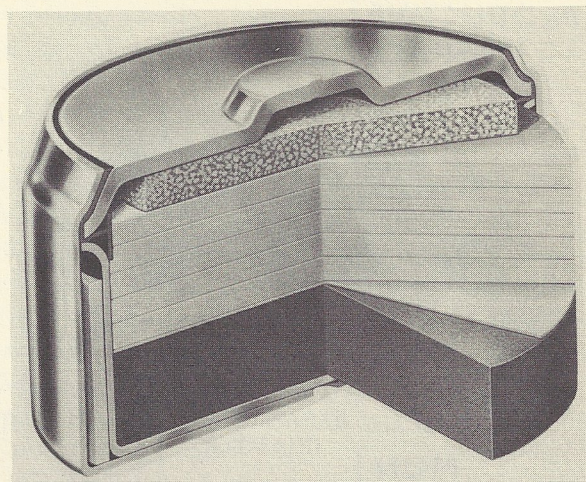
Fig. 5-22

mercury-oxide cell, shown in Fig. 5-23. Mercury-oxide cells, while costing more than the carbon-zinc cells have many advantages. First, they are considerably lighter and smaller than the standard cells (when cells of equal capacity are compared). In addition, they operate over a wide temperature range, the rated voltage of 1.34 volts remains constant during most of the cell's life, and they do not require periods of "rest". The type shown in Fig. 5-23a uses a button of compressed, amalgamated zinc powder attached to the nickel-steel top as the negative electrode. The electrolyte is a solution of potassium-hydroxide saturated with a zincate. The positive electrode, which connects with the nickel-steel outer case, is made of mercuric oxide and graphite. An insulating grommet separates the negative steel top from the positive steel case. The type shown in Fig. 5-23b uses the same materials, except that the negative electrode is made from a zinc foil. Thin sheets of zinc foil are corrugated (wrinkled) and wound around and around, as shown in Fig. 5-23c, with a strip of absorbent material that has been soaked in the electrolyte. In this way, a very great area of the zinc comes into contact with the electrolyte. This adds considerably to the capacity of the cell.

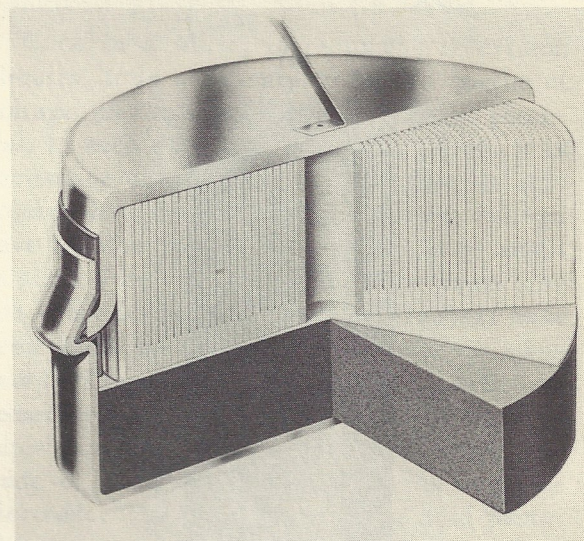
Mercury-oxide cells are used by the Armed Forces for "walkie-talkie" radios, for guided missiles, and in other places where weight and size are important. In civilian production, at least one manufacturer uses them to power wrist-watches, and they are widely used by hearing-aid manufacturers.

5-12. AIR-CELL

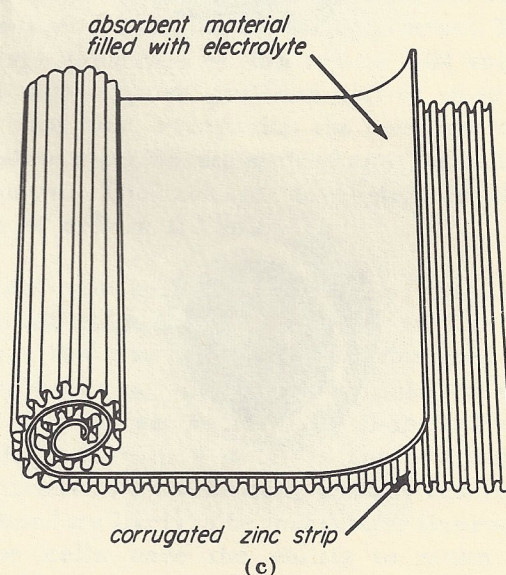
This cell, while classed as a primary cell, cannot be called a dry cell. Even though



(a)



(b)



(c)

Fig. 5-23

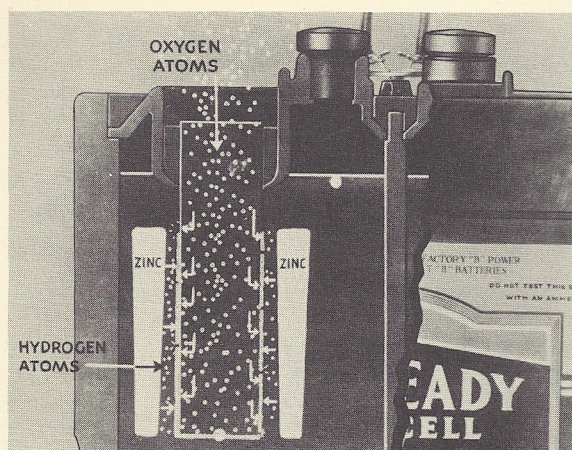


Fig. 5-24

it is shipped dry and kept dry until sold and put in use, the electrolyte, in a working cell, is decidedly wet. As shown in Fig. 5-24, the negative electrode is zinc. The electrolyte is a caustic alkaline solution of sodium hydroxide, and the positive electrode is porous carbon. (This means that the carbon has a lot of little holes in it.) This cell is put into service by adding ordinary drinking water to the level indicated by the manufacturer. It requires a well-ventilated room, because it draws oxygen from the air for depolarizing instead of using a depolarizing agent.

This cell is designed to give long life where the current drain is not more than 0.65 amperes. The voltage output is about 1.25 volts a cell. They are widely used for telephone switchboards, railway signals, and in radio stations.

5-13. TEMPERATURE

One condition that affects the output and the life of cells and batteries is temperature. Most batteries and cells are designed to operate at greatest efficiency at normal room temperature (70°F). At temperatures of 100°F and above, cells may deliver slightly higher voltages, but they wear out much faster. At very low temperatures, from 0°F and below, the chemical action slows up greatly and cells do not deliver the power that they do at normal temperatures. One of the advantages of the mercury-oxide cell is that it can operate efficiently at higher and lower temperatures than the standard carbon-zinc cell.

5-14. STORING CELLS

Cells are best stored in a cool place, because this tends to slow up any chemical action that occurs while the cell is not in use. In a shop where batteries are kept for sale to customers, cells should be kept on one of the lower shelves (if there are several) because, as heat rises, the upper shelves are likely to be warmer. When a fresh supply of cells is received, be sure that the cells already in stock are placed in front of the shelf so that they may be sold before the fresh stock is put on sale. In ordering cells and batteries, do not order large quantities of unusual types of cells and batteries. Keep a low stock of those that sell slowly. Remember, very small cells, such as the pen-light size, have a short shelf life.